

Life as a Self-sustaining Collective Chemical Transformation

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Abstract

This paper proposes a new hypothesis in theoretical biology that may provide a new understanding of life. It conjectures that in the living cell, chemical transformations influence each other in a constructive manner by producing non-random molecular motion. Contrastingly, in inanimate matter, different molecules move randomly and independently of each other during chemical reactions. The orderly molecular rearrangements come from the interactions of valence electrons and nuclei that jointly solve the many-body problem. They transform potential energy into mechanical work, and move each other when they construct minimum potential energy configurations. As all the molecules belonging to the cell are integrated into a single orderly arranged body, these efforts combine and produce collective rearrangements, in which various segments of the cell move with respect to one another in orderly ways. In the living cell, these rearrangements perform vital functions. With their help, the organism extracts nutrients from the environment, distributes them across its own body, controls their chemical conversion, creates new functional structures, and integrates them into its body. The primal activity of the living cell is its own renewal. The organism replaces used elements with fresh ones in order to produce new actions aimed at maintaining its structure and function. In essence, life can be regarded as a self-sustaining collective chemical transformation. The notion of the collective rearrangements may provide a strict definition of life and open the way for the creation of a quantitative theory of living matter.

Keywords: collective chemical transformations, definition of life, difference between animate and inanimate matter, origin of life, driving force of evolution.

Statements and Declarations

Not applicable.

Presently, chemistry and molecular kinetics exist separately because in usual substances chemical transformations do not cause any ordered motion of molecules.

In this paper, I will argue that in living biological cells, chemical transformations produce orderly molecular movements and organize collective rearrangements, which in return control the course of chemical reactions. In this case, chemistry and molecular kinetics must be combined into a single theory, which should describe constrained rearrangements of the chemically transforming condensed bodies. I suggest that the development of the corresponding mathematical models can produce a comprehensive theory of life.

The development of the new theory is a formidable task. In this manuscript, I will only outline the basic aspects of the problem. I will justify the need for the new theory and specify the range of phenomena that it must explain. I will describe in mere words complex mathematical entities that can be suitable for this purpose. I will try to predict some of the results of the required theory.

1 Aristotle's De Anima

Approximately 2370 years ago, Aristotle articulated the difference between animate and inanimate matter (Polansky 2007). In short, animate organisms willfully generate their own actions, aimed at maintaining their structure and function, whereas inanimate matter does not take any purposeful actions.

After the invention of the microscope, scientists determined that this description holds at the cellular level. The commonly accepted sign of life is the cytoplasmic streaming, which facilitates transport of molecules and organelles around the cell (Goldstein and van de Meent 2015). To be alive, the cell must perform mechanical work and move its body parts in an orderly fashion.

Modern biology suggests that the orderly rearrangements of animate bodies occur at smaller length scales, going down to the atomic level. These movements carry out a number of vital functions. In particular,

they implement the extraction of nutrients from the environment and the excretion of waste products from the living body. The orderly rearrangements of the cellular body transport chemical precursors, and control metabolic chemical transformations, they build new structures from raw materials, and integrate them into the living body.

This paper conjectures that animate and inanimate matter display different behaviors at the molecular level: The animate matter generates orderly and organized non-Brownian rearrangements, which produce constructive actions. Contrastingly, inanimate matter makes only random Brownian movements. Next, I will answer the question where these orderly movements come from.

2 Collective Chemical Transformations

From a physical perspective, a stable atom consists of electrons that rest in the potential well created by the charged nucleus. An electron can rest on two nuclei simultaneously, in which case it creates a chemical bond. However, the valence electrons can do more than merely connecting atoms. They can reorganize matter. They perform mechanical actions when they fall to lower potential energy states during irreversible chemical transformations.

Normal chemical transformations take place in inanimate substances. There, different molecules move as disconnected Brownian particles. They mix by chaotic thermal fluctuations and react by chance.

Animate matter is different. In the living cell, all molecules are orderly arranged and are connected by means of physical and chemical bonds. In the single condensed matter body, different tumbling electrons will have to move and rearrange the entire cell. While doing so, they will affect each other's actions. Most often, they will act at cross purposes, producing no observable animation. In suitable structures, however, their actions become coordinated. In this situation, they will generate perceptible collective transformations, in which different subgroups of the falling electrons will operate in succession, and the entire condensed body will execute a sequence of different movements (The Neural Network as an Active Condensed Matter Body [\[hal-01575993v2\]](#) 2017).

The living organism uses the orderly collective rearrangements to manipulate chemical reagents and control metabolic transformations. It builds new structures and reorders itself. This is not all. It also rearranges its environment in orderly ways, and extracts new nutrients. It utilizes their potential energy to sustain its own activity. From this perspective, the living organism is a self-sustaining group of cooperating elementary animate agents — the falling valence electrons — that constantly dismiss old, and accept new active members (Leibniz and Rescher 1991).

Here, I have explained the essence of my hypothesis. In what follows, I expand my explanation, present some supporting arguments, and discuss the consequences of the hypothesis.

3 The Source of Autonomous Actions

In most situations, it is enough to assume that condensed matter is composed of atoms and chemical bonds. However, when matter undergoes joint chemical and mechanical transformations, these elements become unsuitable. More generally, condensed matter is composed of the valence electrons and atomic nuclei shielded by core electrons.

The valence electrons and the shielded nuclei interact through electrostatic forces. The mutual positions of these interacting elements is one of the solutions of the equation of motion (here, many-particle Schrödinger equation). This “many body problem” has multiple solutions. Which of these solutions will the system choose?

We know from physics that a system of interacting particles will undergo a process, in which it moves to occupy the lowest available potential energy level. In simple terms, the system will fall down into the deepest attainable potential well. This process is irreversible because the transition from a higher energy to a lower energy state converts potential energy to kinetic energy. The system uses this energy to perform mechanical work, reordering atoms.

The condensed matter body is restricted by numerous internal constraints. (The interconnected atoms obstruct the motions of the condensed matter body.) It means that the body controls the actions of the interacting valence electrons and nuclei. It allows them to make only certain collective rearrangements. The shape and structure of the body determine its function.

4 The Principle of Operation of a Living Organism

The orderly rearrangements of biological bodies may control chemical transformations. Here I explain the main consequence of this effect.

The distinguishing feature of the collective chemical transformations is that the coordinated groups of falling electrons can accumulate enough energy to pull some of the valence electrons out of their deep potential wells, thereby breaking stable chemical bonds. Thanks to this capacity, animate matter attains new packing options and discovers new atomic configurations with even deeper potential wells. Different organisms use different protocols for ordered manipulations of matter. They synthesize different products. However, any of these manipulations pack atoms more efficiently compared to random reconstructions.

I believe that this particular activity describes the operating principle of living organisms. They rebuild small molecules (obtained by normal chemical reactions), make more energetically efficient products, extract mechanical work in the process, and use it to sustain their own activity.

Consequently, the body of a simple one-celled organism is denser and better packed compared to its water-based habitat. The organic products manufactured by the living cell have higher molecular weights because they were produced by large cooperating groups of the falling valence electrons.

5 Observable Properties of the Animate Cell

The living cell can be regarded as a specially arranged condensed matter body that manipulates its own constituents. It makes orderly reconstructions, and reconstructs its habitat. It extracts the desired

chemical components from the environment, builds new ordered structures, and integrates them into its own animate body.

The body of the cell is composed of water reinforced with organic compounds. It can be viewed as a highly ordered and very heterogeneous polymer structure, which contains many different components. The surrounding water is also an ordered polymer. Only this polymer is more homogeneous, less ordered, and less robust. It can be mixed much easier (Pollack 2013).

The living cell generates orderly rearrangements. It makes internal rips, separates moving parts from its own body, transfers them to new places, and then reattaches them by means of new chemical bonds. Then it makes new rips, carries out new material permutations, and so on.

The “loose parts” of the living cell, which at first glance appear as Brownian particles, are not Brownian. Instead of random rips, and aimless chaotic motions, they make ordered movements.

5.1 The consequences of the orderly reconstructions

The autonomous reconstruction of living bodies is an observable microscopic phenomenon (Woodhouse and Goldstein 2013). In this paper, I generalize this effect. I conjecture that animate bodies generate ordered rearrangements at all length scales starting from the atomic scale. At the molecular scale, the cells manipulate chemical precursors embedded in their own bodies, and synthesize compounds that cannot appear accidentally in inanimate matter. *The living and dead cells synthesize different chemical products.*

The constructive acts continue at mesoscopic scales, where cells arrange freshly manufactured molecules, and build structures that cannot appear in inanimate matter haphazardly. *The living and dead cells build different structures.* (Fig. 1)

There is one important point. In addition to the ordered reconstructions, cellular bodies undergo regular Brownian-type chaotic rearrangements caused by thermal fluctuations (The Physics of Life. Part 1: The Animate Organism as an Active Condensed Matter Body [\[hal-](#)

[01575989v2](#) [1], 2017). Living organisms constantly repair the inflicted damages. Additionally, cells always contain “completely loose parts”. Those include oxygen, carbon dioxide, various ions, and other small molecules. They diffuse right through the organisms’ body. These detached molecules are needed for the normal operation of the organism. However, they do not belong to the organism.

5.2 The unique capacities of the falling electrons

The collective reconstructions endow condensed matter with amazing new capabilities. Consider an atom that wants to replace an energetically unfavorable (dissatisfying) chemical bond. To do so, it should find itself a new partner, break the existing bond, accomplish an atomic transposition, and build a new chemical bond. It would never achieve this goal on its own. However, it can do all of that in partnership with a large group of cooperating transforming atoms. The reconstructing condensed body will help the atom to break the bad bond, push away the dissatisfying neighbor, select a more satisfying atom, and make a new bond.

By the sequences of the collective reconstructions, the group of cooperating atoms will satisfy the needs of the majority of its members. They will end up in a more energetically favorable configuration, and create a more effectively packed structure.

Every single valence electron aims to put its atomic neighborhood in order. Acting together, these electrons will make their common condensed body more ordered. I assume that this particular effect causes self-ordering of living matter.

5.3 Condensation

The fundamental physical force that animates matter originates from the capacity of the atoms to condense, i.e. to link together by chemical bonds, and create arranged condensed matter. In physical terms, biological life is driven by the process of self-sustaining collective chemical condensation.

In the simplest case, the orderly self-supporting collective condensation involves adding of lacking chemical bonds to an already existing condensed matter body. This happens, for instance, in folding proteins (Alberts et al. 2002).

A more complicated case of non-random collective condensation takes place in condensed matter bodies that have many unsatisfactory bonds. Such bodies store significant amounts of potential energy. They generate various mechanical actions by making collective reconstructions.

The growth of a living body also boils down to the organized collective condensation. Growing organisms appropriate new atoms from their habitats producing better-packed condensates in their own bodies.

5.4 Independent wills of animate organisms

In my opinion, it is safe to say that the “desires” of the valence electrons to fall to the charged nuclei produce the wish of the animate body to make a voluntary action. This desire combines from myriads of individual desires of various charged particles to construct lower potential energy configurations.

In a biological organism, mostly carbon, oxygen, and hydrogen improve their chemical bonds. Therefore, it is safe to say that the wills of the organisms mostly arise from the individual atomic wills of these particular elements.

In addition to the internal desires, the organisms’ actions are determined by the internal constraints, set by the intrinsic structures of the organisms. The organisms may also use DNA and other similar guides. Thanks to the genetic codes, they make exact predetermined actions.

In this part of the manuscript, I described the cell as a piece of animate matter. I did not yet explain where the first animate body came from. This will be explained in the last part of the manuscript, in which I suggest the blueprints of the simplest organisms. Now I describe communications between the elementary animate agents.

6 Communications between Active Agents

6.1 Signals in transforming biological matter

When the falling electron reconstructs its chemical bond, it moves the neighboring atoms. In a big three-dimensional macromolecule, these movements affect other chemical bonds. These movements can be regarded as signals. They are produced by particular sources (transforming chemical bonds), and assimilated by particular recipients (unstable chemical bonds). They have very unusual properties. On the one hand, they are delocalized during motion. On the other hand, they are absorbed by particular localized recipients when they interact with matter.

Additionally, these signals transport matter and can be regarded as peculiar mobile elements of condensed matter. Such elements appear in any transforming condensed matter that undergoes stimulated transformations. They emerge, for instance, in nuclear fuels. In these compounds, the decaying nuclei emit neutrons, which cause new nuclear fission events. The neutrons may be regarded as the mobile elements of condensed matter.

The nuclear and the intramolecular signals both carry interactions between transforming elements. However, they differ in one very important respect. In nuclear reactors, different neutrons move independently of each other. Consequently, nuclear fission proceeds through sequences of simple irreversible events connected by simple causal links. Those are known as chain reactions. In contrast, in biological matter, different signals bind together and mix. As a result, all irreversible events connect, and create a densely interlinked causal network. Every irreversible transformation has many causes and many consequences. And that is not all.

The animate cell constantly modifies its own structure. Correspondingly, it constantly changes the communication channels between the sources and the recipients. At any moment, some processes may stop affecting each other; some previously disconnected processes

may become connected. The exact mathematical description of such evolving substances is very difficult.

6.2 Collective permutations

In my paper entitled “The Physics of Life. Part 2”, I attempted to identify a particular solution of this complex problem (The Neural Network as an Active Condensed Matter Body [\[hal-01575993v2\]](#) 2017). I said that the collective reconstructions should resemble localized atomic permutations. The collective reconstruction should proceed roughly as follows. The condensed body spontaneously makes a rip in itself, forces out a piece of material from itself, transfers it to a new place, and reattaches it to its body by means of new chemical bonds. The empty space, which was left after the initial rip, is filled with new material, and is also restitched with new chemical bonds. This process is illustrated in Fig. 2.

6.3 Rearrangements in chemically inhomogeneous substances

This section articulates the key idea of this paper. Here I describe collective rearrangements that occur in chemically inhomogeneous matter. In this special case, the transferred pieces carry chemical precursors. Upon reaching their destinations, these pieces cause new chemical reactions and trigger new collective rearrangements. The full reconstruction of the chemically inhomogeneous body will proceed as a cascade of chemically stimulated permutations. This situation is illustrated in Fig. 3.

The collective reconstruction of a chemically inhomogeneous substance will look like directional transfer of certain mobile metabolites. At the molecular length scale, the animate organism will resemble a collection of chemically active molecular bodies — the sources and recipients of various mobile metabolites — that communicate via certain chemical signals. Only, the chemical signals do not move randomly. They are involved in a complex regular motion. All the rips and permutations pertaining to the animate state (1) are not accidental, they are generated by the living body; (2) are aimed and

directional; (3) are interrelated. All the individual chemical and structural transformations are integral parts of one big orderly transformation of the animate body.

6.4 Multiscale reconstructions

In real biological cells, different small transformations combine into larger collective processes for several times (West 2017). Every time they do so, they produce a new level of integration. Eventually, they produce a cell-wide autonomous reconstruction known as cyclosis or cytoplasmic streaming (Goldstein and van de Meent 2015). This self-sustained mechanical movement is seen through a regular microscope.

Modern biological cells are multiscale systems; they produce multiscale reconstructions. At every length scale, the reconstructions proceed with different speeds. The bigger is the length scale, the slower is the characteristic reconstruction. The fastest processes occur at the atomic scale: it takes approximately 10 nanoseconds to create a new chemical bond (Zaikov et al. 2006). In comparison, it will take approximately 10 microseconds to generate a signal between two neurons (Bullock et al. 1977).

Evidently, the creation of cooperating groups does not stop at the cellular level. It goes on further, producing multicellular organisms. The condensed bodies made of cooperating cells produce even more complex collective reconstructions. Perhaps, the most complex multicellular reconstruction is the operation of a human brain. The brain is an evolving (transforming) condensed matter body composed of living neurons that establish and break material bonds with each other, exchange electrochemical signals, and generate complex coordinated actions.

In my paper entitled “The Physics of Life. Part 2”, I suggested that the brain generates collective reconstructions in the same manner as simple animate bodies produce collective moves at the atomic scale (The Neural Network as an Active Condensed Matter Body [\[hal-01575993v2\]](#) 2017). From this, I described the emergence of the “collective mind”, and explained how this collective entity controls the individual neurons.

6.5 Peculiar characteristics of biological signals

One has to keep in mind a very important point. The biological signals are not exactly signals. Or rather, they are not only signals. In addition to pure information, they carry energy and matter. In strict physical terms, they are mobile elements of the transforming condensed matter. In chemically inhomogeneous matter, they are mobile metabolites.

This should be true for all different signals at all different length scales, including the elementary signals emitted by the falling valence electrons. In my papers entitled “The Physics of Life”, I imply that one could create a universal theory of animate matter, equally applicable to any length scale, including the atomic scale (The Animate Organism as an Active Condensed Matter Body [\[hal-01575989v2\]](#) 2017, The Neural Network as an Active Condensed Matter Body [\[hal-01575993v2\]](#) (2017)).

7 Transition from the inanimate state to the animate state of matter

7.1 The first animate working body

It is generally believed that, in cells, transforming organic molecules perform most actions, whereas water remains relatively inactive. This may be true for modern cells, which manipulate matter mostly with the assistance of protein-based molecular machines.

However, this may not have been the case for primordial proto-cells. Chemical transformations may occur in water, directly. In this situation, water may acquire the capability to carry out basic ordered rearrangements, to manipulate its own constituents, and to synthesize new types of organic molecules. To have such a property, water must be a poorly ordered polymer.

I hypothesize that the earliest animate “working body” was water. Water may have been the first compound that crossed the boundary between the inanimate and animate realms. It did so when — in addition to totally random rearrangements — it started to produce some non-random rearrangements.

As a matter of fact, I believe that ocean water still remains at this divide today: in some situations it behaves as a disordered solution, and in other situations it acts as an ordered polymer. The non-random reconstructions occur in water under some special conditions (Miller and Urey 1957).

7.2 Increasing complexity of the first animate body

Figure 4 illustrates the primordial animate condensed matter body. This poorly ordered polymer is composed of water and some low-molecular-weight precursors. It undergoes collective condensation by producing new organic molecules with increased molecular weights. The primordial animate body accumulates these molecules, becoming more intricately structured. Consequently, it may produce increasingly more complex and more diverse products. Each subsequent condensation event occurs in a better-ordered configuration. Therefore, the orderly condensing body may self-organize and increase its regularity at a growing pace. (This will only work up to a certain limit. The excessive accumulation of organic condensates may eventually introduce internal conflicts and cause chaos.)

The increase in structural complexity comes from the interacting subatomic particles, which collectively solve the many-body problem by performing ordering atomic reconstructions. During the collective condensation, this order materializes in tangible structures. The larger is the number of irreversible condensation events, the greater is the amount of objectified structural order.

7.3 The measure of evolution

The orderly condensation explains the emergence of more complex — and more diverse — forms of life. There is one additional effect known as evolution.

Evolution implies emergence of more advanced living species. But what does “more advanced” actually mean? The organisms that occupy higher levels of evolutionary development are supposed to be more efficient in surviving in complex and hostile environments.

It may happen that the “level of perfection” has a measure at the atomic and molecular scales as well. The organism’s “working body” may evolve into something more advanced.

Here is my hypothesis. The organism’s working body takes a step up along the evolutionary scale when it achieves a higher level of organization. It means that its atomic, molecular and mesoscopic transformations diminish mutual conflicts, enhance cooperation, and create larger ensembles. The working body enhances the agreement between its animate agents. Correspondingly, it executes more complex, more extensive, and better coordinated actions.

In measurable physical terms, better-organized animate bodies reach higher degrees of chemical condensation, which means that the superior organisms produce better packed condensates with better (more energetically favorable) chemical bonds. They increase the degree of processing of raw materials, meaning that they transform initial precursors into more intricately arranged products. They get more efficient in harvesting the abilities of the valence electrons to perform constructive actions.

At the macroscopic scale, more advanced organisms become more productive, and, therefore, more competitive. They become the fittest. In this regard, evolution is caused by mutations, competition between different organisms, and natural selection. However, the root cause of any development is the ordering acts of the interacting subatomic particles.

7.4 Primordial water-based organisms

The earliest organisms must have had much lower degrees of condensation. They had simpler metabolisms. The earliest organisms contained smaller amounts of organic compounds; and those compounds had lower molecular weights. The organic condensates, produced by the first organisms, were less ordered, and formed poorer ordered arrangements. It means that the earliest animate matter was exposed to greater numbers of random processes, and implemented less accurate actions. In other words, *it was much closer to the inanimate state.*

On the bright side, due to the lack of guiding structural components, such as DNA, the primordial organisms could modify their internal structures during their lifespans. Almost certainly, they were capable of very fast evolution.

7.5 Contemporary cells

Perhaps, the contemporary biological organisms contain less water and more organic components; these organic components have higher molecular weights, and are better packed. The advanced cells fabricate a wider range of molecular products, and build more intricate structures from these products.

The superior organisms execute more elaborate and more accurate actions at the molecular and atomic length scales. They can synthesize increasingly complex compounds with higher precision. *In brief, through evolution, animate organisms get farther away from the inanimate state.*

8 The Simplest Organisms

From a mathematical perspective, the self-sustaining transformation of the living body is a dense evolving network of irreversible elementary events connected by causal relations. This causal network does not allow any significant reduction of variables because this procedure implies elimination of the cause and effect relationships. I.e., in order to describe a biological system by a small number of parameters, one needs to assume that the molecules move freely of each other, and the chemical reactions occur independently. In this case, the theory of collective chemical transformations turns into normal chemistry and kinetic theory of liquids. In simple terms, by reducing variables, one cuts the organism into a vast number of disconnected pieces. This kills life and eliminates all biological effects.

Here, I will try to bypass the reduction of variables problem. I will replace biological cells by model systems that consist of simpler elements, which perform much simpler transformations. Consequently, I will obtain quasi- and pseudo-living objects, which generate much simpler self-sustaining actions. Nevertheless, the model systems may

help to understand the operating principles of real biological organisms. From a mathematical point of view, this procedure corresponds to a replacement of variables.

The replacement of real biological matter by the simpler counterparts has serious negative consequences. The description of biological processes becomes very abstract or even metaphorical. Many readers will find this unpalatable. I apologize in advance for this inconvenience.

In this part of the paper, I propose the model blueprints of the simplest organisms. For the aforementioned reasons, these organisms will be very different from familiar biological cells.

8.1 The entanglement

The orderly collective reconstructions can only occur in specifically arranged bodies. As a rule of thumb, in usual materials, the elementary animate agents act at cross-purposes. The bodies that cannot produce any orderly collective reconstructions will be called “entangled”. To enable collective movements, they must be “disentangled”. This disentanglement occurs in living organisms when they rearrange matter at the atomic and molecular scales.

The emergence of life corresponds to the appearance of the first disentangled body. I will discuss the spontaneous disentanglement shortly. But before I do so, I will explain how existing organisms disentangle themselves. This process was described in detail in my paper entitled “The Physics of Life. Part 2” (The Neural Network as an Active Condensed Matter Body [\[hal-01575993v2\]](#) 2017). Here is a brief recap.

8.2 Collective rips

An autonomous action starts from a rip in the organism’s body, in which many chemical bonds break one after another. The ripping resembles a break of a dam. The broken bonds eliminate some internal constraints. The removal of the constraints activates a new batch of inhibited agents. They rock the body and open the rip further. As a result, the rupture expands in an avalanche-like mode.

The action ends when the body begins to restore the broken bonds. The healing of the rip may also resemble an avalanche, when one restored bond shrinks the tear, and triggers formation of next bonds.

The spontaneous rupture of the animate body is the simplest case of disentanglement. The healing of the rupture corresponds to the simplest entanglement. Therefore, the living body constantly entangles and disentangles itself. The entangling corresponds to the inhibition, whereas the disentangling corresponds to the activation of the animate body.

Generally, any condensed matter body containing a significant amount of unsatisfactory chemical bonds has a potential capability to disentangle itself through spontaneous ruptures. In favorable circumstances, such bodies could trigger spontaneous collective processes. However, the probability of such events depends on the degree of entanglement, and in many situations remains small.

8.3 Emergence of the organism in weakly entangled systems

Consider a weakly linked body that makes spontaneous ruptures and produces collective reconstructions. Each of these reconstructions will bring it to a new configuration. In a sequence of reconstructions, the structure of the body will change, like a kaleidoscope pattern. Generally, after several reconstructions, the body will change beyond all recognition.

However, not all reconstructions change structures out of recognition. Some special arrangements generate reconstructions that bring the body to the “almost original” formation. In other words, the configuration of the body after the reconstruction will closely resemble the configuration before the reconstruction, only composed of different elements. These special reconstructions simply replace some used elements with fresh equivalent elements. Consequently, the specially constructed bodies will repeat the same reconstructions over and over again.

In my paper entitled “The Physics of Life. Part 1”, I called these special arrangements “recurring configurations”; they produce

“recurring reconstructions” (The Animate Organism as an Active Condensed Matter Body [\[hal-01575989v2\]](#) 2017). I have also argued that these specially arranged bodies correspond to biological organisms. Indeed, biological organisms periodically generate similar actions. These actions maintain and restore the structure and function of the organism. A more detailed discussion of this issue can be found in my manuscript entitled “The Physics of Life. Part 3: The Artificial Animate Materials” ([\[hal-02541236\]](#) 2020).

The general structure of the organism will be described in the following sections. Here I explain the emergence of the first organism. The aimlessly evolving material body described at the beginning of this section may undergo modifications, try many different configurations and eventually find one of the recurring states. As soon as it reaches such configuration, it will establish the recurring reconstruction, and reinforce it by repetition. In my opinion, this particular course of events describes the emergence of life. The entire process is driven by the collective condensation. However, it does not involve aimed self-organization. Instead, it is a trial-and-error process.

One important note should be made here. The original aimlessly transforming animate body has no goal and attains no specific objective. The organism, on the other hand, produces purposeful actions. Namely, it restores its own structure and function. The primary goal of the organism is its own survival.

In my paper entitled “The Physics of Life. Part 2”, I have shown that the recurring reconstructions may further disentangle the organism and make it more complex (The Neural Network as an Active Condensed Matter Body [\[hal-01575993v2\]](#) 2017). In other words, the organism can grow and evolve. This happens because every reconstruction leaves a trace in the living body, and these changes accumulate with repetition.

8.4 Emergence of life in model systems

Many non-biological transforming condensed matter systems generate orderly collective reconstructions. In many situations, these reconstructions can become self-supporting. In this context, biological

animate matter has many non-biological relatives. These simple counterparts of living matter duplicate biological-like self-organization, including the spontaneous emergence of life. These effects were described in my papers entitled “The Physics of Life” (Parts 1, 2, and 3) ([\[hal-01575989v2\]](#), [\[hal-01575993v2\]](#), [\[hal-02541236\]](#)).

My primordial organisms appeared in weakly-entangled chemically inhomogeneous condensed matter. In my experiments, a small disentangled region of such substance produced a specific self-sustaining chemical (or pseudo-chemical) transformation, and a mechanical reconstruction. This “seed recurring reconstruction” had strong disentangling and ordering effect. It induced new transformations in its surroundings, and subjugated them by means of special signals. The disentangled region grew in size by incorporating these new transformations into an “organized system of transformations” (thus, the organism). Importantly, this condensed matter body periodically repeated similar reconstructions. Thanks to that, the organism maintained a stable structure and a stable metabolic network. Fig. 5 illustrates the growth of the organism.

My experimental demonstrations had one weak point. I used very simple non-biological materials instead of real biological matter:

In my manuscript entitled “The Physics of Life. Part 1”, I suggested that — in addition to real elementary animate agents (i.e. the falling valence electrons) — there are other, much simpler pseudo-animate agents (The Animate Organism as an Active Condensed Matter Body [\[hal-01575989v2\]](#) 2017). Those have analogous properties, but much simpler behavior. The simplified agents are very convenient. However, they use other types of motive power. For that reason, these agents are not “living” in the strictest sense. The real animate agents, on the other hand, are too difficult to handle.

8.5 The pseudo-animate granular matter

Now I briefly describe my pseudo-animate model system. Above all, in order to be “animate-like”, transforming condensed matter must generate non-random reconstructions. Many material systems have this

property. The simplest material system that generates non-random ordering reconstructions is the granular matter of the hourglass. (Fig. 6) It is composed of two types of elements: grains and voids. Under gravity, the grains aim to fall down, whereas the voids strive to rise up, like little bubbles. Being constrained by the walls of the glass, the grains make physical bonds with each other, and create the condensed matter body. The voids have the capacity to disconnect the grains, and destroy the condensed state. The tumbling grains hinder each other. The voids remove the obstructions, and facilitate motion. In short, the grains and the voids have opposite properties.

The flow of grains and voids in the hourglass makes a self-sustaining reconstruction as shown in Fig. 6. At the center of the funnel, the tumbling grain crosses the boundary between “the condensed matter body mostly composed of grains” and “the condensed matter body mostly composed of voids”. The material exchange is bilateral. It injects a new void into the jammed matter composed of grains. The void stimulates the recurring reconstruction that brings the next grain into the funnel. In the stream of the hourglass, the rising voids act as signals that permit motion. The tumbling grains may be regarded as feedback signals. The entire collective reconstruction realizes a circulation of these mobile signals (The Animate Organism as an Active Condensed Matter Body [\[hal-01575989v2\]](#) 2017, The Artificial Animate Materials [\(hal-02541236\)](#) 2020).

Simultaneously, the moving grains and voids act as mobile metabolites. The moving stream of the hourglass realizes a sequence of small pseudo-chemical transformations: The propagation of grains and voids involves stop-and-go motions. An unobstructed grain moves a short distance before it meets a new obstacle and stops. In each of these steps, a fraction of the grain is transformed into its opposite, and the rest goes further. Therefore, the stream of the hourglass can be regarded as a simple non-biological counterpart of a biological metabolic chain.

8.6 The simplest recurring reconstruction in a chemical system

A similar self-sustaining reconstruction can spontaneously emerge at a boundary between two substances with different chemical composition. A small section of this boundary can produce the reconstruction that implements the exchange of two moving metabolites as shown in Fig. 7.

When a piece of the first material crosses the boundary and enters new chemical environment, it triggers a certain chemical transformation, and creates another moving metabolite with opposite properties. This new metabolite crosses the boundary in the opposite direction. In the first medium, it triggers another chemical transformation, creates the next moving metabolite, and sends it back to the second medium. Then the initial permutation of pieces will induce the next permutation of similar pieces, and the whole process will become self-sustaining.

Just like in the granular matter of the hourglass, the metabolic transformation of the moving metabolites may proceed in several steps as illustrated in Fig. 7.

8.7 The exchange of metabolites between the organism and habitat

The boundary between two chemically different substances could be regarded as the border between the primordial organism and its habitat. (Fig. 8) The exchange of metabolites across the boundary represents feeding. The metabolic chain of the organism generates a special signaling metabolite and injects it into the environment. In a chemically suitable habitat, this metabolite must cause a particular chemical transformation, and create a specific response metabolite that must get back to the organism. The organism digests this serving of food using its internal metabolic chain, and generate the next signaling metabolite, and so on.

I contend that Fig. 8 is the blueprint of the simplest living organism in the simplest habitat.

The blueprint of a living organism must contain: (1) the structure and chemical composition of the organism's body; (2) the structure and chemical composition of its typical habitat; (3) the characteristic movement of metabolites, and their chemical and structural transformations, in the body of the organisms and in the body of the habitat.

I define the simplest living organism as the animate condensed matter body that feeds by exchanging metabolites with its environment.

8.8 The simplest permanent organism

The simplest organism described in the previous section has a major flaw. It has a short lifespan because it needs to release its own matter into the environment.

A permanent organism may appear in a slightly more chemically inhomogeneous medium, as shown in Fig. 9. The organism must realize two different exchanges with its habitat. At one interface, it gets the first nutrient. In its own body, it transforms it into the product, which is used as a signaling molecule at the second interface. This signaling molecule stimulates the habitat, and brings the serving of the second nutrient. In this organism, the metabolites move in a closed loop; and this motion creates a self-sustaining circulation of signaling and metabolic molecules. The organism undergoes the perpetual reconstruction; it cycles the habitat's material through its own reconstructing body.

8.9 The reproduction of the simplest organisms

The permanent organism may accumulate material and grow in size. Additionally, it may create parallel metabolic chains as shown in Fig. 10. These chains may carry similar metabolites and produce similar reconstructions. In my paper entitled "The Physics of Life. Part 1", I suggested that similar reconstructions interfere (The Animate Organism as an Active Condensed Matter Body [\[hal-01575989v2\]](#) (2017)). They also tend to build impermeable borders. By doing so, they stop hampering each other. This mutual interference may eventually cause separation. The organisms' reproduction is NOT mere replication of molecules. It

occurs when one self-sustaining reconstruction (one organism) releases a new self-sustaining reconstruction (an offspring organism). First, the organism grows and accumulates the interfering segments. Then these segments form a new self-sustaining circulation of metabolites. After this, the transforming body divides into two disconnected parts.

8.10 Collective organisms

On rare occasions, one can observe a phenomenon, which is the exact opposite of the division. Two or more reconstructing bodies may combine into a single body and produce one common reconstruction. This happens when these reconstructions are fully compatible. Instead of interfering, they mutually enhance each other.

To establish a collective organism, different cooperating organisms must build material connections with each other, and create a common condensed matter body. This is accomplished with the help of condensation. Then the reconstructions must elaborate a common collective behavior by modifying the structure of their shared body. They must eliminate the disagreements (by building internal walls in the right places), and remove the isolating barriers between the cooperating parts. In principle, two different biological cells may fuse into a single cell. Perhaps, this happened when mitochondria became integral parts of complex cells, and when chloroplasts became organelles of algal cells (Cornish-Bowden 2017, Buchner 1965).

It must be said that full cooperation between different reconstructions is very rare. More commonly, different cells attain only partial cooperation. In this case, they create multicellular organisms. In a multicellular organism, every cell retains its own (partially independent) internal reconstruction. The cells may also create an evolving multicellular condensate that changes its structure and function. That is the animal brain. The operation of the brain is described in my paper entitled “The Physics of Life. Part 2” (The Neural Network as an Active Condensed Matter Body [hal-01575993v2](https://arxiv.org/abs/1705.01575) (2017)).

8.11 The artificial collective organisms

In my papers entitled “The Physics of Life” (Parts 2 and 3), I described my experimental attempts to create the collective forms of pseudo-life in my model systems ([□ hal-01575993v2 □](#), [\(hal-02541236\)](#)). At the beginning, I made individual animate-like forms that operated at an interface between two chemically different media as described in Section 8.6. Then I tried to combine them into cooperating ensembles and observe their collective reconstructions.

My proof-of-concept experiments were rudimentary as I used only the simplest available tools and equipment. They require thorough verification. Nevertheless, my efforts appear to have been at least partially successful. It is possible that, with proper development of materials and techniques, I will be able to fabricate complex forms of non-biological artificial life through this process. My final goal is to demonstrate their complex adaptive behavior.

9. Conclusions

In describing inanimate matter, chemistry and kinetic molecular theory may exist as two independent scientific disciplines. This separation is justified because in inanimate objects, chemical transformations do not regularize molecular motion.

In this paper, I tried to argue that in the living cell, in which all the elements are integrated into a single orderly arranged body, the chemical transformations and molecular movements are interrelated. In this case, chemistry and molecular kinetics should be integrated into a single theory that may require a new set of mathematical techniques.

In order to combine conventional chemistry and molecular kinetics, I have introduced a new model that describes orderly collective rearrangements of orderly arranged condensed matter bodies, driven by the stimulated transformations of the elements. I conjecture that the “orderly evolving condensed matter” can provide a universal language that can describe biological processes at all the existing biological length scales, from the atomic to the macroscopic level. In this article, I tried to

argue that this approach can provide a strict definition of life, and that it can answer fundamental questions of how life originated, and why it evolved into complex forms.

In this paper, I have identified the main difficulty of the new mathematical description. The self-stimulated transformation of the orderly arranged condensed body is a dense network of irreversible elementary events interconnected by a vast number of causal links. This system does not allow any significant reduction of variables. I have suggested a way to circumvent this problem. It involves the replacement of variables. In practical terms, this procedure corresponds to the replacement of real biological organisms by simplified model systems, which consist of simpler elements that undergo much simpler transformations.

I have a good reason to promote this particular approach: The model systems are not mere mathematical abstractions. They have visible and tangible material prototypes, which can be used to create various quasi- and pseudo-living organisms with simplified autonomous behaviors. With proper development, these living-like creatures can perform useful tasks. Eventually, their evolution can lead to the creation of willed sentient robots, which will perceive the environment, solve problems and make decisions like real biological organisms.

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Figures

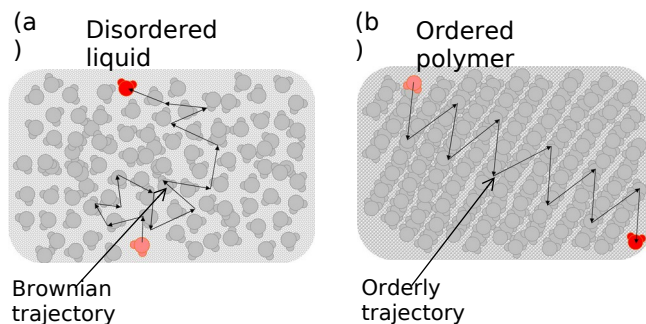


Fig. 1. Inanimate liquid vs. animate matter at the molecular scale. (a) Inanimate matter is composed of unordered molecules. The particles of the liquid make random chaotic movements. (b) Animate condensed matter is composed of oriented molecules held together by means of chemical bonds. The animate body makes ordered reconstructions. Its particles make ordered movements.

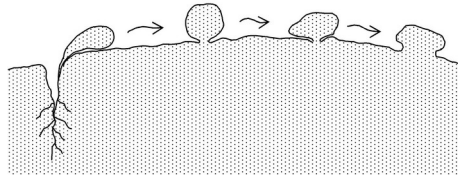


Fig. 2. Autonomous collective reconstruction of the condensing body. The body generates an internal tear, then transfers a piece of itself to a new location.

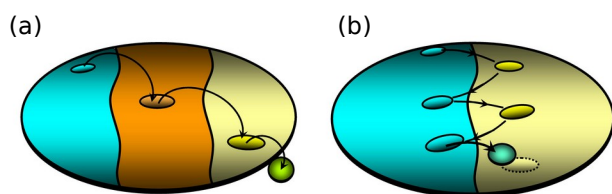


Fig. 3. Collective reconstructions of chemically inhomogeneous animate bodies. (a) propagation and transformation of moving metabolites; (b) back and forth motion and transformation of moving metabolites at the interface between two segments with different chemical composition.

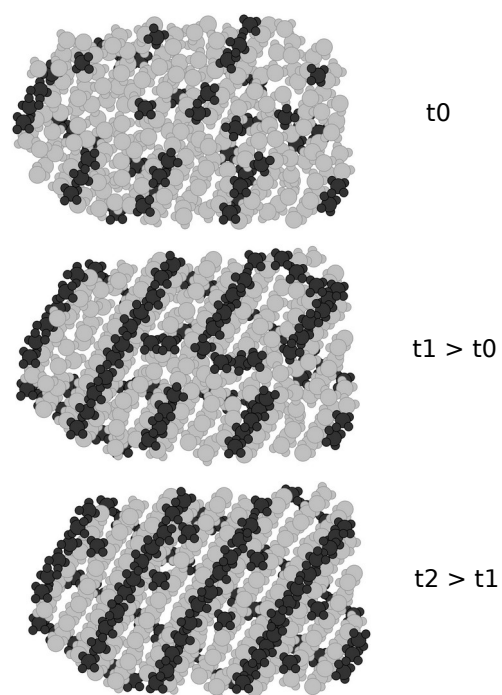


Fig. 4. Condensing water-based animate body at the molecular scale. Accumulation of ordered organic condensates orders the body.

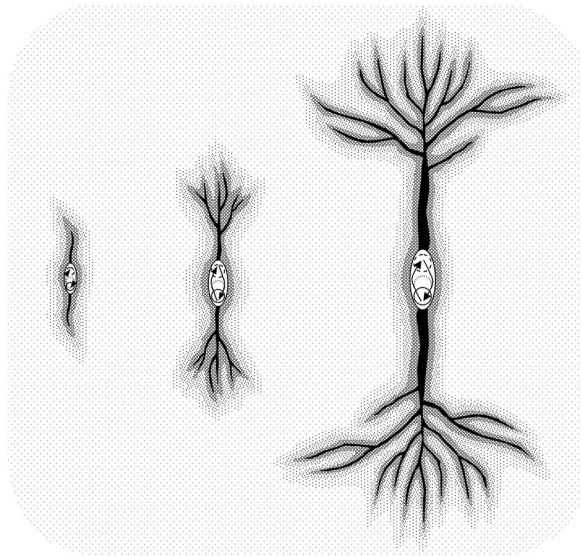


Fig. 5. The emergence and growth of the organism from a small recurring reconstruction. The seed ordering reconstruction disentangles its inanimate habitat. These changes accumulate over time. The disentangled parts of the habitat become parts of the organism.

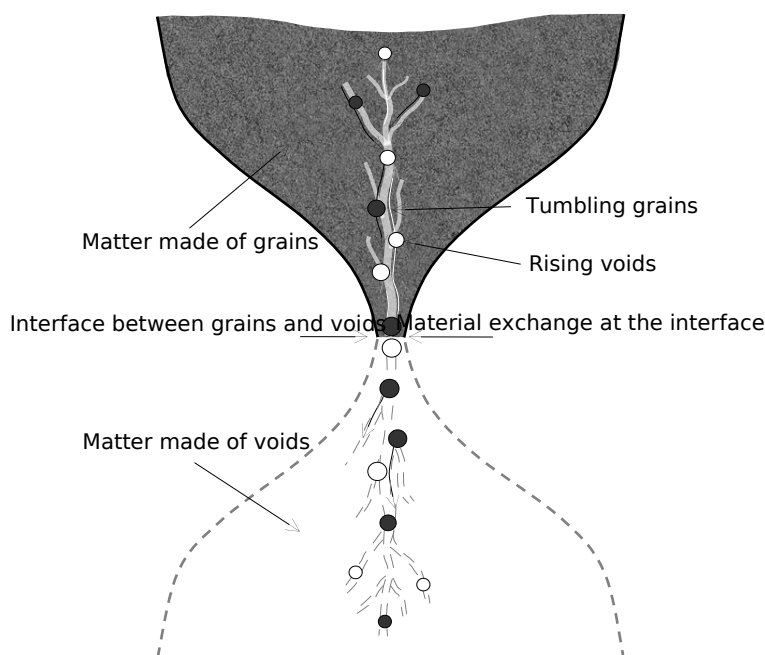


Fig. 6. The active stream in the hourglass, which can be regarded as the simplest prototype and the mechanical analogue of an animate organism. Under gravity, the grains and voids become pseudo-animate agents. The seed recurring reconstruction appears in the funnel, where the grains and the voids trade places. The stream periodically brings the next grain into the funnel. Thus, the total reconstruction is self-sustaining. The separation of matter into the disentangled pseudo-organism and its entangled (jammed) habitat exemplifies the emergence of life.

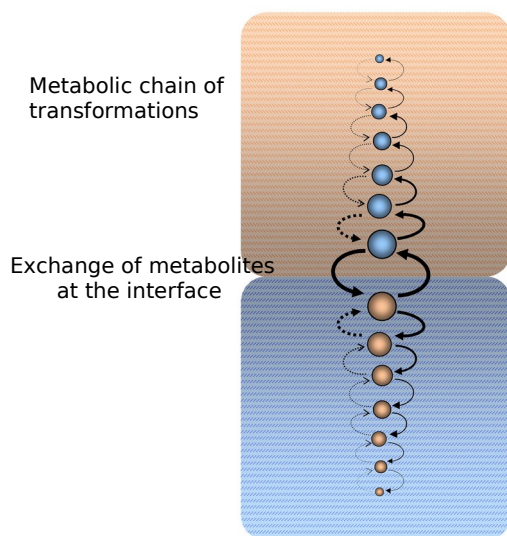


Fig. 7. Self-sustaining recurring reconstruction at the boundary between two media with different chemical composition. The metabolites cross the boundary, and then turn into their opposites through simple metabolic chains consisting of several steps.

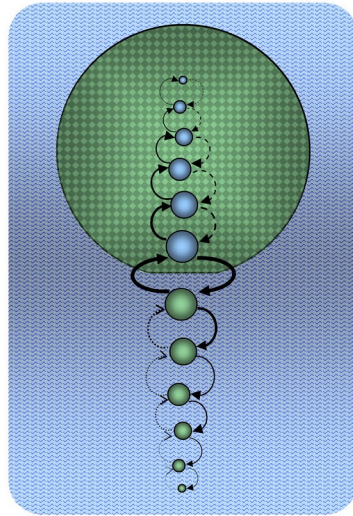


Fig. 8. The simplest organism in the simplest habitat. The single metabolic chain of the organism generates a special signaling molecule and then releases it into the environment. The chemically suitable environment generates a response metabolite, which sustains the entire reconstruction. Thus, the organism feeds.

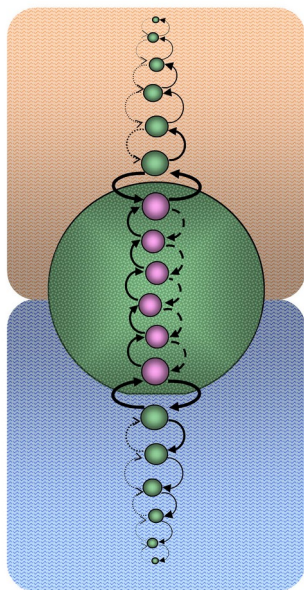


Fig. 9. The perpetual organism, which acts as an intermediary between two substances with different chemical composition. The organism contains its own internal circulation of metabolites, realizes two material exchanges with its habitat, and creates two different metabolic chains in the habitat. From two different interfaces, it obtains two different types of food, and emits two different types of stimulating chemical signals.

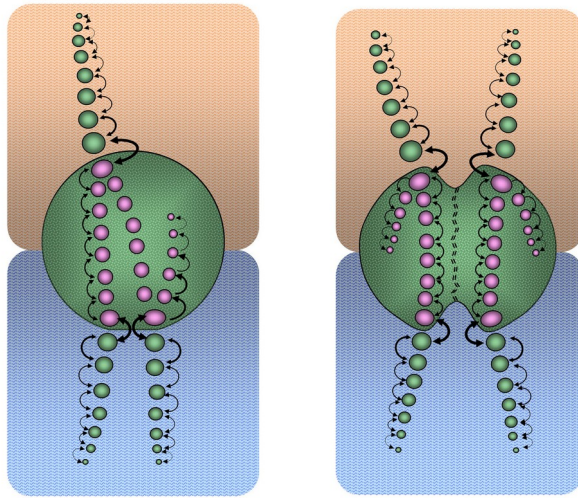


Fig. 10. Division of the animate condensed matter body caused by the emergence of a competing reconstruction. The two self-sustaining reconstructions build an impermeable border.